Analysis and Research on the Thermal Properties of Energy-efficient Building Glass: A Case Study in PVB Laminated Glass

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Abstract: A new kind of PVB-laminated glass is introduced as an energy-efficient building glass. Based on tests and calculations of the shading coefficients of flat glass, LOW-E coated glass and PVB-laminated glass with different thickness, their effects on room base temperature and cooling load of the residential buildings in the hot-summer-warm-winter zone are simulated and analyzed. Compared with flat glass, the PVB laminated glass shields 44 percent of the solar radiation from entering the room and reduces 40 percent of the shading coefficient. At the same time, 28 percent of the cooling load, 21 percent of installed capacity and 8.6 percent of full-load operation time can be saved.

Keywords: PVB laminated glass, Thermal properties, Room-base temperature, Cooling load

1. INTRODUCTION

Building glass, like other kinds of transparent constructions, are more and more wildly used in modern buildings. It is reported that[1] in the year of 2001, around 7,500,000 square meters of glass curtain wall are produced (used) in china, approximately 2/3 of the total production in the world. Until the end of 2001, 42,000,000 square meters of glass curtain wall are set up in our country. The style of glazing units has developed from simple ones in the past days to variety nowadays, LOW-E glasses, PVB glasses, double or triple-glazing insulated glasses and other kinds of glasses came out one after another.

At the same time, the living standard is greatly improved. As a result, the building energy consumption also increases. In the year of 2000, energy consumed in buildings reaches 356 million tons of standard coal in China, 27.8% of the total social energy consumption and around 1/3 of the value of the developed countries. The level of Guangzhou, 30%, is a little higher than the average level of the country. [2,3]Therefore, glazing units make more and more notable effects on the energy consumption of the whole building. It is considered to be a most emergent task to control the quality of energy usage, based on the experiments on thermal properties of them.

In this paper, the residential buildings in Guangzhou are taken as an example. The thermal properties and their effects on energy consumption of several kinds of glazing units, such as clear glass, Low-E coated glass and PVB laminated glass with different thickness, are analyzed. The methods on usage of energy-saving glass are promoted based on the differences of their thermal properties. Meanwhile, a new kind of glass—PVB laminated glass (Fig.1), is introduced.

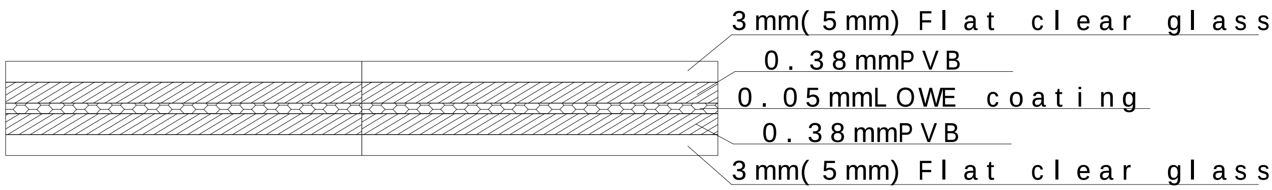

Fig. 1 Structure of PVB laminated glass

2. EVALUATION STANDARDS OF SOLAR-OPTICAL PROPERTY

The main request to thermal properties of glazing units in hot-summer-warm-winter area can be concluded as following: natural lights should transmit as much as possible so as to satisfy the indoor lighting demand while the solar radiation is reflected to outside. That is, in the precondition of keeping visible light transmittance stable, the cooling load of solar radiation through glazing units is decreased and the air-conditioning consumption in summer is reduced[4]. Therefore, the most important point in designing energy efficient glazing units in this area is to strengthen their abilities of solar radiation control. Generally, the following indices are used to evaluate their thermal properties:

2.1 Light transmittance τ_v

It indicates the transmittance capability of glass, coating and other kinds of transparent constructions in the spectrum 380nm～780nm(visible light). According to [5,6], τ_v can be calculated using the following formula:

$$\tau_v = \frac{\int_{380}^{780} D_\lambda \cdot \tau(\lambda) \cdot V(\lambda) \cdot d_\lambda}{\int_{380}^{780} D_\lambda \cdot V(\lambda) \cdot d_\lambda} \approx \frac{\sum_{380}^{780} D_\lambda \cdot \tau(\lambda) \cdot V(\lambda) \cdot \Delta\lambda}{\sum_{380}^{780} D_\lambda \cdot V(\lambda) \cdot \Delta\lambda}$$

(1)

where, $\tau(\lambda)$ is the spectral visible light transmittance, D_λ is the relative spectral power distribution of illuminant D_{65}, $V(\lambda)$ is the photopic luminous efficiency function defining the standard observer for photometry, $\Delta\lambda$ is the spectral bandwidth.

2.2 Shading Coefficient *SC*

It is defined as the ratio of the total solar energy transmittance *g* of glass or glazing units with coatings and other hi-tech improvements to *g* of 3mm normal flat glazing. It shows the change of solar energy after transmitting these constructions. The total solar energy transmittance of 3mm glass is prescribed as 88.9% [5].

2.3 Solar Heat Gain Coefficient *SHGC*

It refers to the proportion between the total inner heat gain through glass, including refraction and absorption, and the outer heat quantity. It shows the ability of accepting solar radiation.

2.4 Thermal conductance *K*

It is composed of the heat transfer coefficients towards the inside and outside respectively and the heat transfer coefficient in the construction itself. In the case that the position of glazing is vertical, ε_i=0.83 and the wind velocity of outside surface is approximately 4*m/s*, the value of he and hi is 23$W/(m^2 K)$ and 8 $W/(m^2 K)$[6] respectively.

2.5 Room base Temperature

It shows the room's thermal properties in the effects of passive thermal agitation. Thus, it can reflect the effects on air-conditioning energy consumption by different factors of the envelope, like material, orientation, shapes and so on. In this paper, based on the simulation results of DeST-h, the varieties of room base temperature in different glazing units in various window-to-wall rates are compared. As a result, the differences in energy saving among them can be gained.

3. TESTS AND ANALYSIS OF THERMAL PROPERTIES OF SEVERAL KINDS OF ENERGY-EFFICIENT GLASS

3.1 Test and analysis of solar-optical properties

Flat clear glass, LOW-E coated glass and PVB laminated glass with different thickness are taken as samples. All the optical data, such as spectral transmittance and reflectance of the samples, in this paper are tested by spectrophotometer, as is shown in Fig.2~3. The total solar energy transmittance and shading coefficient are calculated in response to standard [5, 6], as is shown in Tab. 1. Spectrophotometer is a special equipment used to measure optical transparent materials such as glass, lens and prism. The spectrophotometer in the experiment is equipped with an integrating sphere, which ensures highly accurate measurement from 175~2600nm.

From Tab. 1, the value of shading coefficient and total solar transmittance of LOW-E coated glass and PVB laminated glass are much less than clear glass. Thus, the heat-insulating property of these two kinds of glass is better. But, the value of solar direct absorptance is much higher than clear glass. If large scale of them is employed in the glass curtain wall, big thermal stress should be produced. It is quite easy to break the glass. Architects should pay special attention to this problem in the stage of design.

Tab.1 Solar-optical properties of the tested glass

Items	12mm Clear Glass	8mm Clear Glass	6mm LOWE Glass	7mm PVB laminated Glass	11mm PVB laminated Glass
Hemispherical Emissivity	0.89	0.89	0.43	0.84	0.84
Visible Light Transmittance τ_v, %	85.97	88.65	81.18	64.12	57.89
Visible Light Reflectance ρ_v, %	8.35	8.87	8.26	8.08	7.12
Solar Direct Transmittance τ_e, %	72.93	80.22	53.80	41.87	30.34
Solar Direct Reflectance ρ_e, %	7.38	8.06	6.85	6.56	5.95
Solar Direct Absorptance α_e, %	19.69	11.72	39.35	51.57	63.71
Total Solar energy Transmittance g, %	78.01	83.24	61.92	52.52	43.50
Shading Coefficient *Sc*	0.88	0.94	0.70	0.59	0.49
Solar Heat Gain Coefficient *SHGC*	0.77	0.82	0.61	0.51	0.43

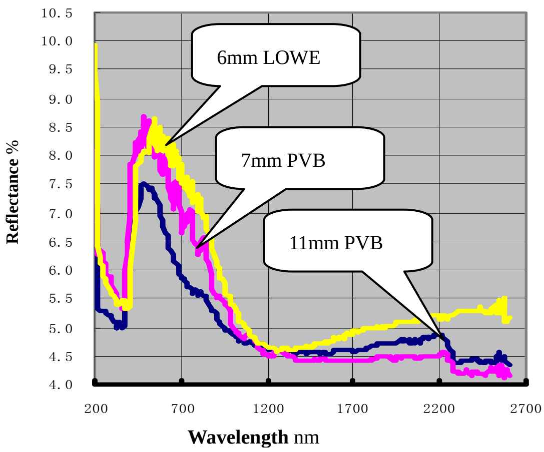

Fig.2 Curves of spectral reflectance

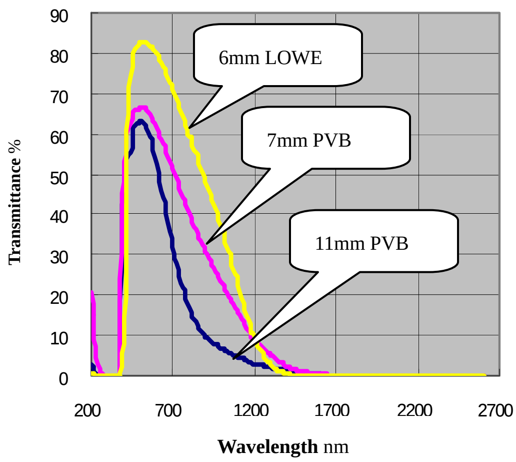

Fig.3 Curves of spectral transmittance

The spectral reflectance, as shown in Fig.2, is closed to each other. In the spectrum of visible light, the reflectance of 11mm PVB laminated glass is lower than the other two glasses. Totally in the whole spectrum, 6mm LOW-E coated glass reflects most lights, 7mm PVB laminated glass takes the second place, while 11mm PVB laminated glass comes the least.

As seen in Fig.3, in the spectrum above 1500mm, that is the near infrared band, the spectral transmittance of them are approximately zero. It can be illuminated that the heat-insulating property of these three kinds of glass is pretty good. In the spectrum of visible light, the transmittance of 11mm PVB laminated glass is obviously lower than the other two. As a result, natural lighting may not be able to satisfy the inner illumination standard and artificial lighting may need to employ

3.2 Simulation and analysis of room base temperature

In order to evaluate the energy-saving properties of them more detailed, the energy simulation software DeST is employed to calculate their room base temperature of the middle storey of the whole building, in the worst condition that the window-to-wall ratio is 1, in the city of Guangzhou. The heat gain from lighting and other equipments, people inner room is not taken into account in simulation. Fig.4~6 shows the monthly-average annual inner temperature, maximum of the monthly inner temperature and the annual distribution of the room base temperature.

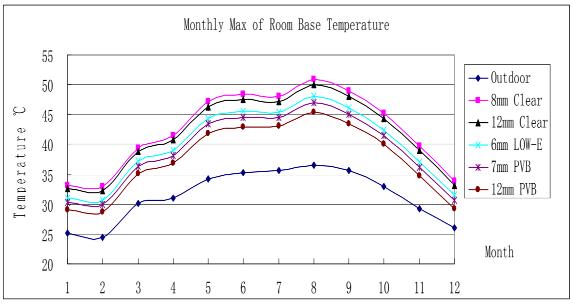

Fig.4 Monthly max of room base temperature

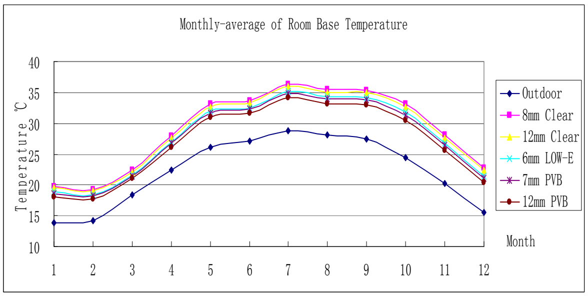

Fig.5 Monthly-average of room base temperature

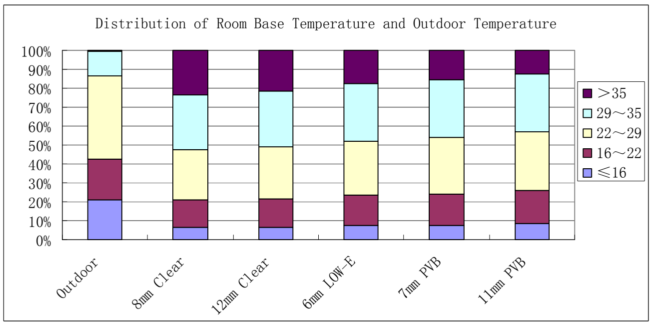

Fig.6 Distribution of room base temperature and outdoor temperature

It can be concluded from the Fig. 4~6 that the annual room base temperature of 8mm clear glass is much higher than the other glass. Its max of monthly-average and monthly-max temperature is 2.4 ℃ and 5.6 ℃ higher than 11mm PVB laminated glass respectively. Therefore, the ability to control the change of inner temperature of 8mm clear glass is weaker than other samples. In the point of annual distribution of room base temperature, the proportion under non-air-conditioning temperature, that is 29℃, of 11mm PVB laminated glass is most of all while the proportion of above the extreme high temperature, 35℃, is least. From analysis of the contribution of the monthly-average and max of room base temperature, the difference in controlling outdoor solar radiation is directly displayed. Thus, the energy-efficient property can be also detected. According to the results in Guangzhou, 11mm PVB laminated glass can save most energy, 7mm PVB laminated glass and 6mm LOW-E coated glass take the second place, while clear glass comes the least.

3.3 Simulation and analysis of cooling load

In order to make a clear guide for choosing proper energy-saving glass and calculate the time period for recovery of investment in future practice, after obtain the room base temperature of different glazing products in the worst condition, the annual cooling load and the max of annual cooling load with different window-to-wall ratio are simulated. The envelopes' thermal parameters of the model in DeST are listed in Tab. 2. The results are shown in Fig.7~10.

Meanwhile, the cooling load of the building, whose window-to-wall ratio can satisfy the mandatory requirements in relevant building orientations in [7，8], is set as a baseline. Fig.11~12 shows the cooling load under different window-to-wall ratio.

Tab.2 Thermal parameters of the envelopes

	Heavyweight walls	Lightweight walls	Roof
Thermal Parameters	*K*=2.0，*D*=3.0	*K*=1.0，*D*=1.5	*K*=1.0，*D*=2.5

Note: *D* is the index of thermal inertia, *K* is the *U* factor.

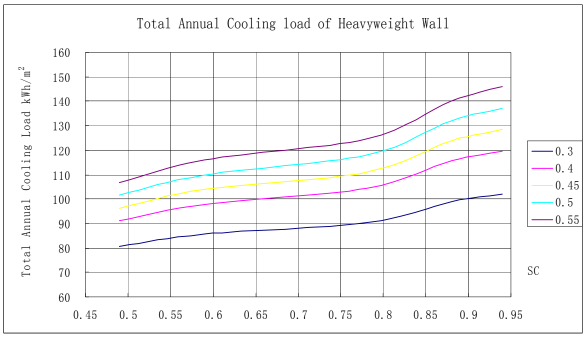

Fig.7 Total annual cooling load of heavy weight wall with 03~0.55 window-to-wall ratio

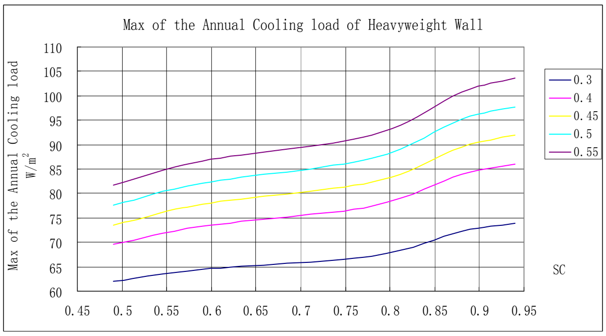

Fig.8 Max of annual cooling load of heavy weight wall with 03~0.55 window-to-wall ratio

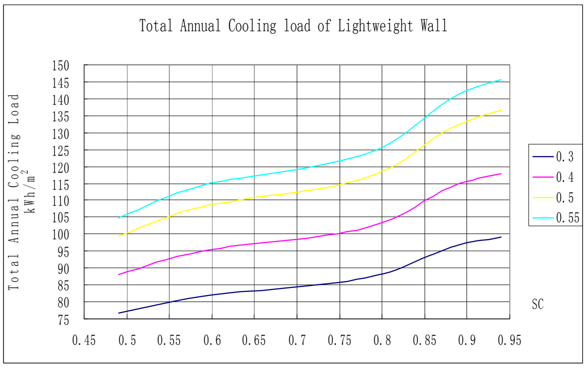

Fig.9 Total annual cooling load of lightweight wall with 03~0.55 window-to-wall ratio

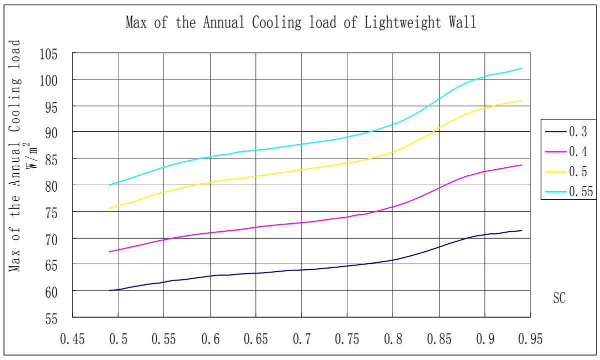

Fig.10 Max of annual cooling load of lightweight wall with 03~0.55 window-to-wall ratio

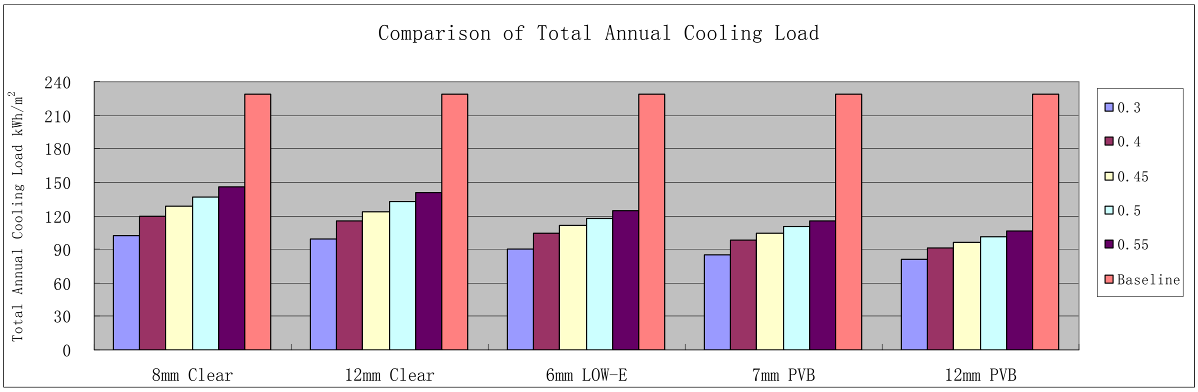

Fig.11 Comparison of total annual cooling load

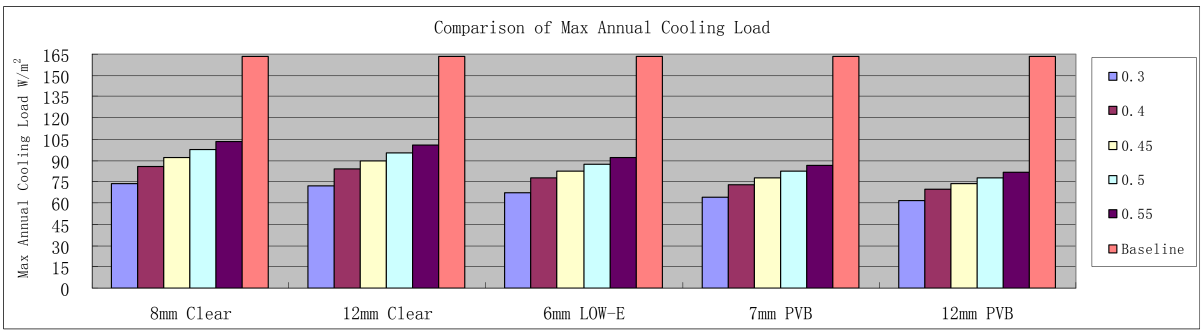

Fig.12 Comparison of max annual cooling load

As shown in the figures above, as the window-to-wall ratio or shading coefficient become larger, the cooling load correspondingly increases. The largest amplitude can reach 31.8% and 27.9% respectively. The less the window-to-wall ratio is, the less change in cooling load because of using different kinds of glazing products. The amplitude would be around 16%~28%. In the condition of same window-to-wall ratio, the utilization of energy-efficient glazing units can not only save 20% power consumption in air conditioning, but also decrease 15% installed capacity and 5% full-loaded operation time. Therefore, although increasing investment in the envelope, employing energy-efficient glass in hot -summer-warm-winter zones, such as Guangzhou city, can obviously reduce the investment in air-condition machines and operation fee.

4. CONCLUSION

Based on the results of tests and calculation of shading coefficient of clear glass, LOW-E coated glass and PVB laminated glass, their effects on the room base temperature and cooling load in hot-summer-warm-winter zone are analyzed.

According to the analysis above, this kind of PVB laminated glass obtains not only the safety like other laminated glass, but notable energy-saving capability. Compared with clear glass, it can prevent 44% of solar radiation entering indoor, reduce 40% in shading coefficient. Meanwhile, in the field of choice and operation of air-conditioning machines, it can decrease 28% of cooling load, 21% of installed capacity and 8.6% of full-loaded operation time.

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